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MODERN MANUFACTURING EQUIPMENT OF THE ERNST HEINKEL AIRPLANE WORKS

By A. Thormann and H. Jockisch

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MODERN MANUFACTURING EQUIPMENT OF THE ERNST HEINKEL AIRPLANE WORKS*

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This report contains a description of new methods of fabrication, new equipment, and special tools, with a view to supplying data for design from economical points of view, as well as to stimulate the interest of other factories in improved shop methods.

I. METHOD AND TOOLS FOR CHANGING THE SECTIONAL SHAPE OF LIGHT-ALLOY AND STEEL TUBES

The inception of the methods dates back to the demand made about three years ago to bring about some sort of standardization in the tubular attachment fittings of light-metal tubes with a view to quantity production and interchangeability of design. This aim was achieved through certain refinements of the old methods employed in the manufacture of such tubing; namely, expansion of the inside diameter with a mandrel or reduction of the outside diameter by means of a drawing die. While both operations cannot be made simultaneously by this method, which is habitual with Heinkel, the outside diameter can, however, be reduced first, say, and then the inside diameter given the desired dimensions. In contrast to the drawing process, there is no waste of tubing when shaping the end, since the tube itself is not drawn through the die, but the drawplate is pushed over the tube, which is firmly clamped in its unchanged part. This method is termed outside drawing (or contraction). If the drawplate is replaced by a mandrel, the tube is drawn from the inside (or expanded).

So far as the construction at all permits, only the dimensions specified for grade 11 (ISA) are required. Since

*"Neuere Fertigungsmittel der Ernst-Heinkel-Flugzeugwerke G.m.b.H." Luftfahrtforschung, vol. 15, nos. 1 and 2, January 20, 1938, pp. 83-90.

the manufacturing tolerances of tubes in their absolute value are smaller than the permissible departures (up or down), tubular shafts require only outside drawing (contraction) and tube holes only inside drawing (expansion). If greater accuracy (grade 8) is specified, a change of shape is effected in such a manner that, by outside drawing the expansion is effected first and, by inside drawing, the contraction first. Both processes are effected in one operation through suitable arrangement of the tools.

The dimensions of the tools must be so determined that the size of the subsequently drawn tubing remains within the desired limits. Owing to the elastic springback of the material, the tool dimensions do not agree with the nominal dimensions of the piece of work. For higher requirements on accuracy (grade 8) they are determined empirically, whereby material as well as diameter and wall thickness must be considered separately.

The design of the drawing tools is conceivably simple although the tools do make severe demands on the quality of workmanship as regards surface, accuracy, and wear resistance. (Here the pioneer work was performed by the C. H. Bernhardt Special Tool factory, Dresden, and the success of the method is in a large measure due to their efforts.) The operation of the tools is shown in figure 1.

For inside drawing (or expanding) to D_i diameter H 11, only a mandrel is used; for outside drawing (contracting) to D_o diameter h 11, a drawplate is sufficient. For more accurate (inside expanding drawing), say, to D_i diameter H 8, the mandrel is followed by a drawplate, which first reduces the diameter from the outside so that on return of the tool the mandrel gives the desired inside dimension. For outside drawing (contracting), as illustrated in figure 1, the process is, of course, reversed. The subsequent drawing of the tube ends is appropriately made on a vertical hydraulic press, which offers the simplest solution for smooth operation and satisfactory lubrication of the tools. A drilling-oil emulsion (50 percent) is used.

The working speed should not exceed 1 m/min, to allow the material sufficient time for form changing. For the starting and return movements, the higher speed easily obtainable with hydraulic presses is useful and therefore recommended for economical reasons.

The pressures necessary for the drawing of thin-walled tubing commonly used in airplane design range up to about 2 tons.

Employed for shaping the process is the same as for drawing, though the necessary pressures may, depending on tube diameter, wall thickness, and degree of contraction, assume values approaching the stability of the original tube. By dividing the contraction process into several stages interspersed with heat treatment, very elaborate form changes can be effected.

In new constructions it is frequently necessary to find the pressure required for a certain contraction in advance, so that a decision may be made as to a particular machine and the number of necessary stages. To follow this process mathematically is very difficult and the attack of this problem by some competent party is earnestly desired. For the present Heinkel follows a formula which, in the explored cases varies < 15 percent from the experimental values:

$$P = \frac{\pi}{4} k \frac{\sin \alpha + \mu}{\sin \alpha \cos \alpha} \frac{(\epsilon^4 - 1)}{\epsilon^2} D \, s \, \sigma_{0.2}$$

where

P is contracting pressure (kg)

k, material constant

$\epsilon = \frac{D}{d}$, degree of contraction

μ, coefficient of friction

$\sigma_{0.2}$ yield point (kg/mm²)

D, d, and s in mm (cf. fig. 2).

The material constant k ranges around 1.6 for the tools used by Heinkel. The design of the tools is governed by the angle of contraction α and the probable coefficient of friction. With predetermined degree of contraction, the contracting pressure is conditional on the factor $\frac{\sin \alpha + \mu}{\sin \alpha \cos \alpha}$. Thus figure 3 shows the influence of the contraction angle on the contracting pressure for different μ.

The high surface pressures rule out fluid friction ($\mu \cong 0.2$). The best contracting angle, even with regard to form rigidity was found to be $\alpha = 15^{\circ}$.

The limit value of the degree of contraction follows from the condition

$$\left(1 + \frac{\mu}{\sin \alpha}\right) \frac{1}{4 \cos \alpha} \frac{\epsilon^4 - 1}{\epsilon^2} k = 1$$

whereat the pressure of contraction would become equal to the crushing limit of the tube. In practice the diameter is contracted in stages of 10 mm; for tube diameters of less than 30 mm, the stages are 5 mm. To avoid waste of aluminum tubing, the cold hardening caused by contracting is removed after each stage by heat treatment. Even tubes contracted in one stage only are given a final heat treatment. Only after-drawn tubes, that is, those whose nominal diameter has not been changed, are excluded from heat treatment. During the contraction process the original cross-sectional area of the tube is not altogether preserved, since part of the material flows in the direction of the tube axis and so lengthens the contracted tube. The reduction in area approximately follows the empirical formula:

$$\frac{F_1 - F_2}{F_1} \doteq 0.4 \frac{D_1 - D_2}{D_1}$$

Subscripts $_1$ and $_2$ refer to the areas and diameters before and after form change (fig. 4).

Tubes of any origin, provided the material and dimensions are approved for airplane construction, are suitable for after-drawing. According to the investigations in the Heinkel shops on coarse recrystallization in the cold-shaping of light alloys, however, duralumin tubes are not suitable for extended form-changing unless their structure is fine-grained.

The expanding process is similar to the contracting process. Duralumin tubing can also be expanded in original condition (aircraft material 3115.5) up to 8 percent of its diameter. Contracted or expanded tubes can be subsequently drawn with tolerances up to grade 8 in the same way as tubes in the original condition.

The proper preparation within the specified tolerances of the tube ends is almost exclusively carried out in the cited manner by cold-working, whether the tubes are of light metal or steel (VCN, Cr-Mo). It was natural to apply the same method to the calibration of tubes of greater lengths; first, in order to adapt tubular shafts for receiving levers, bearings, etc.; second, to obtain cylinders of thinner walls than are obtainable by machining. Undoubtedly, the tubing purchased from supply houses is accurate enough, but from the point of view of stock-keeping it is desirable to get along with the common commercial products and to do the necessary redrawing in one's own shop. The tools required for this are of the same type as for the redrawing of tube ends. All that is necessary is the proper control so that the fluctuations in wall thickness occurring in the commercial tubes do not lead to rejections. As it pertains to long work, the tools are clamped in a horizontal hydraulic machine of special design. The lubrication is assured by pressure pump. The chief requisite for an unobjectionable finish of the piece of work and careful treatment of the tools is the scrupulous removal of dirt and rust from the tubes before redrawing.

Drawn cylinders are spot-welded onto the cylinder bottom. A cylinder of this kind of 60 mm diameter and 1 mm gage Cr-Mo steel tubing withstood an inside pressure of 280 atm. - equivalent to the strenth of the material - and even then the weld remained undamaged. Figure 5 illustrates the experimental cylinder after machining off the collar on the bottom of the cylinder for a study of the weld. Cylinders of this type offer considerable advantages both as regards weight as well as economy.

Owing to the temperature drop at high altitude the operation of airplane controls is preferably accomplished with rods of material of the same heat expansion as used for the fuselage and the wings. For this purpose especially, the contracting process offers great advantages because it makes it possible to give the push-pull control rods, which are primarily stressed in buckling, a structurally beneficial shape, so that their ends require less space for openings, etc. The number of structural parts, while preserving standardization, can be reduced by rolling in the thread in the contracted end. This possibility is the result of the thickening of the wall on contracting, according to the previously cited formula.

A particularly expedient solution is afforded by the use of contracted push rods with rolled thread in combination with the EHF eyes and adjustable eyes with self-alining bearings (German patent), shown in figure 6. In these the outer ring of the bearings is combined into one with the threaded bolt and made of carburized steel so that only the bearing surface has the necessary hardness while the thread connection itself remains soft and can be drilled with the tube for "safetying" with a pin. The dust protection of the bearing is oil and acidproof rubber or similar material in form of a sliding cover.

Heinkel has now accepted this method for duralumin push-pull rods as standard practice after exhaustive tests had proved their practicability. Six different tubes of 1 mm gage with diameter ranging from 25 to 50 mm were contracted and fitted with M 14 X 1.5 rolled thread. Then eight different tubes of 1 mm gage with diameters ranging from 15 to 50 mm were contracted and fitted with rolled thread M 12 X 1.5. The tubes were tested in tension, compression, buckling, and alternating fatigue load, and checked for cross-sectional area reduction. In addition, the tubing material was tested in original and in finished condition.

The loading arrangement is shown in figures 7 and 8. All tubes invariably failed at the point marked 1, except on the 30 X 1.0 tube with thread M 14 X 1.5, where the break occurred in section A.

Table 1 contains a compilation of the strength test data; the result of the subsequent check is shown in figure 9 as mean value against the corresponding tubes. Figures 10 and 11 show the experimental tubes after buckling.

The tubes intended for fatigue-testing were loaded together with the eye and adjustable eye terminals, according to figure 6. Three 20 X 1 tubes with M 12 X 1.5 thread, twice with and once without check nut were subjected to a load of $P = \pm 200$ kg at $n = 82$ stress reversals per minute. No strain, cracks, etc., were noticed after 100,000 stress reversals.

Two 25 x 1 tubes with M 14 x 1.5 thread, once with and once without check nut disclosed no sign of failure at 100,000 stress reversals.

By the same method were investigated: two 40 x 1 tubes with M 12 x 1.5 thread under ±400 kg load, as well as two 50 x 1 tubes with M 14 x 1.5 thread under ±600 kg load. Neither case disclosed anything objectionable after 100,000 stress reversals.

In figure 12 two push rods of the same size (35 x 1) and identical attachment fitting (pin: 8 mm diameter) are compared. By foregoing all contraction the sample with inserted piece would appear even plumper than the new version.

The success with the push rods prompted the application of the method of contracting the tubes and rolling-in of the thread to other structural parts, such as adjustable struts of 55 x 2 chromium-molybdenum steel tubing. But, owing to the high stress of the tools, it is impossible to roll a thread smaller than M 25 x 1.5 in steel tubing. For rolled female thread in duralumin tubing, the lower limit is M 12 x 1.5.

The contracting process can be carried farther, so that smaller thread-cutting becomes possible. The Heinkel Company, for example, uses a turnbuckle shrunk from 15 x 1 duralumin tubing to 7.9 mm outside diameter and fitted with M 5 female thread. Its failing load was 892 kg, according to tensile tests. The strength of rolled thread is, as is known, 15 percent higher than the thread cut by conventional method.

Tools similar to those used for contraction take care of any necessary flanging. One such flange pressed on to a 30 x 1 duralumin tube for the purpose of holding a spring withstood a failing load of 2,350 kg. The break occurred in the unstrained tube, figure 13.

Such a flange can be continued and put on the inside, as illustrated in the handle, figure 13. The fluting also was effected by drawplate. Following the contraction and calibrating of the fitting end, the grip portion is flanged, contoured and flattened to conform to the turning motions of the hand.

Expansions and contractions of every kind, symmetrical or asymmetrical with the axis of the original tube are feasible.

II. SKIN RIVETING

The Customary Riveting Methods, Range of Application, and Special Tools

The demand for perfectly smooth surfaces, for aerodynamical reasons, has led to a multiplicity of riveting methods. After sufficient experience had been accumulated, the need for some kind of standardization in riveting methods and shop practice became imperative.

In the appended tabulation, figure 14, the riveting methods used by Heinkel are, so far as they have not as yet been included in the statdardiization, indicated by the letters x, y, and z.

The most important types of riveting for covering large surfaces are: mushroom head (P) and flat, countersunk riveting with dimpled sheets (F S x). As regards strength, both are about equal. Economy and quality of workmanship depend upon type and degree of accessibility. The following data serve for their appraisal:

1. Mushroom-Head Riveting (P)

This lends itself to hand and machine operation, figure 15. To assure a satisfactory closing head, rivets of finer than standard length graduation are used; cutting-off therefore is usually inevitable. Moreover, since very short rivets are difficult to insert, the patented mushroom-head rivet-set tool (fig. 16) is employed for machine operations; it combines the rivet shank-cutting tool, the pulling-tight or dimpling tool, and the dolly; hence the loss of time due to changing of tools is a minimum. After the rivet is pulled tight, the free shank is cut to its exact length by the laterally disposed tongs.

However, this type of machine-riveting requires adequate clearance in rivet axis direction, since any deviation of the hammer axis toward the rivet axis, say due to sloping or wrong shape of the snap, results in defective work. On the other hand, in fuselage riveting, the continuously changing position of this axis is subordinate because the snap is correctly guided by the rivet head. Another advantage of this riveting method is that by forming the closing head as a flat, flush head it becomes practically impossible to spoil the rivet.

For driving mushroom rivets by hand the snap holding the rivet head can be the wrong shape, since it merely represents a shoulder of the dolly. For this reason, this method is applicable even in places not readily accessible; but it is expensive and should be used only in special cases. For instance, it takes less time to drive single mushroom rivets by hand than to use a rivet hammer for heading individual F S x.

In such cases a dolly with elastic mass is employed which positively prevents the snap from jumping off the rivet head (fig. 17).

2. Flat, Countersunk Riveting with Dimpled Sheets (F S x)

Only machine riveting.- The process for this is illustrated in figure 18. Given ready accessibility on approximately upright surfaces, this method is about as fast as mushroom riveting. But for overhead or slanting use of the dolly, as in fuselage riveting, for example, the time involved and the danger of inferior workmanship are greater, since the forming of the closing head (F) cannot be watched as closely. In case of restricted accessibility, the F S x machine method is definitely superior; the requisite dollies are adaptable to almost any form and comparatively easy to fabricate. Figures 19 to 21 show various dollies for riveting in places not readily accessible.

The rivets are inserted from the outside, thus eliminating the irksome task of the "threading." It is not advisable to use the lower limit of accessibility given in figure 14 any more than is absolutely necessary, because working with the necessarily thin and light dollies imposes added exertions.

3. Flat, Countersunk Riveting with Countersunk and Dimpled Skin

(F S y/F and R/F S y)

This method is used when the maximum sheet thickness or the maximum gripping lengths for P and F S x are exceeded. The different operating stages are illustrated in figures 22 to 25 for flush rivets and for mushroom-head rivets, once with countersinking beginning at the thickest sheet and then with countersinking beginning at the third sheet. F S y/F in conjunction with F S x is primarily a machine method, while R/F S y in conjunction with P lends itself to either machine or hand operation, depending upon accessibility.

4. Flush-Riveting Dimpled Holes and Driven-In Sheets

(R/F S z)

<u>Hand riveting only</u>: The process is illustrated in figure 26. Standard half-round rivet heads are headed with flat dolly. The sheets are neither countersunk nor dimpled but forced into the equally deforming rivet head by flat driving of the upsetting mushroom or barrel-shaped closing head. Properly executed, the strength of this rivet joint will be sufficient, but since it is impossible to check the quality of workmanship on the finished piece (closing head too flat!) this method should be abandoned in favor of P or F S x on all highly stressed structural parts.

If a contoured rivet head is desired, the DIN L 177 flat, round-head rivets can be used in similar manner (F R/F S z). Then the flat dolly is replaced by a dolly with snap.

III. AUTOMATIC STRIP INSERTION FOR DRAWING-SHEET SECTIONS (PATENTED)

The sections made of strip commonly used in airplane construction can be rolled through separately driven sets of rolls or else be fabricated by drawing. The rolling method offers the advantage of continuous operation, but slight inaccuracies of the rolls are very apt to cause stresses resulting in the rejection of the finished sections. When drawn through dies, the strip materal is severely stressed by the hard transitions and cannot be brought into the complicated forms frequently specified. For this reason the Heinkel Company use, wherever feasible, freely running rolls for the drawing of sections. The only drawback of this method, the loss of time involved, in the threading of a new strip through opening and closing of the top rolls, was overcome with a drive for the top roll which operates only during the insertion process. The drive is derived from the return roll of the traction chain and transmitted over chain drives to the top roll. The transmissions are selected so as to increase the driving speeds from roll to roll and to maintain the speed of the traction chain higher than the driving speed of the last roll. The individual rolls are coupled across a simple claw and freewheeling with their momentrary drive.

This method precludes any compression of the section between the individual sets of rolls during the insertion process; the section is continuously under tension and the entire driving gear runs idle after the section has been gripped by the draw carriage.

Even short pieces of strip can be economically used up in this manner. The clamping device of the drawing carriage is fitted to the section so that there is no waste due to crushing, and making it possible to produce sections of greater length, even on short draw benches by secondary feed.

IV. SILENT (PANEL) BEATING TOOL

Despite the great progress made in the automatic shaping of sections into frames, etc., it is not always possible to avoid manual shaping operations in airplane construction. The conventional pneumatic drop hammers used for these operations have been for years a menace to the health of the workers, quite apart from the effects of the penetrating noise on the nerves of all other workers in the shop. Consideration for the welfare of the employees has at last prompted the use of forces other than by blows. It was found after exhaustive studies that the well-known action of the toggle lever press promised quickest results. And the very first experimental machine developed on this principle proved successful. The necessary shaping tools themselves remained as before. The drive gives the upper tool holder a stroke of 1.2 mm with a frequency of 700 blows per minute. The action of the individual pressures is controlled by the spacing of the two tools at dead center and regulated by vertical adjustment of the bottom tool. This adjustment is effected by a simple screw spindle with foot-pawl operation. The adjusting force necessary for this is moderate, since adjustment can be made only in the pressure-free part of the stroke and the end pressures are absorbed by self-locking of the spindle.

The upper tool being movable upward and sideways, the drawing pressure can be applied at any desired point of the section. This adjustment is obtained by supporting the upper tool holder in a double eccentric whose two adjusting levers are easily operable. Since with a stroke of only 1.2 mm the clearance in the joints would permit of no satisfactory operation and cause disturbing noises, the upper tool holder is provided with a spring of high oscillation frequency, which acts against the driving pressure.

The framework is designed for 50-ton maximum pressure and fitted with a safety device for 30-ton ultimate load. The motive power for this range is 5 horsepower. The machine not only meets the requirements as regards absence of noise but actually increases the quality of production considerably. Jerky feeding by hand is impossible because of the high frequency; the section passes through almost automatically if the section is pushed ahead steadily, affording a smooth, uniform surface. Judged by the experiences gained thus far, a 50-percent greater output over the conventional air hammers is anticipated. Not being bound to the uneconomical compressed air, the machine can also be used for portable plants; it likewise eliminates keeping a number of rarely used form-fitting tools in stock, which is of vital importance in experimental design. For instance, U-shaped arcs of 2 mm sheet thickness, with an 80 mm web height and 30 mm flange width heretofore shaped from sheet over form-fitting tools can be obtained more economically by driving from previously beveled channel sections.

V. BEAM STRAP MILLING MACHINE

The butt straps of beams usually wedge-shaped for statical reasons can, of course, be fabricated as a rolling mill product, but such ready rolled plates are practically out of the question in experimental construction; first, because the restricted number of such plates required would make an order for rolling uneconomical, then too, delivery could not be had immediately. For this reason, the Heinkel Company had the firm of Paul Knopp, Berlin S W 19, develop and construct a milling machine which meets the requirements satisfactorily and makes the tedious and at the same time expensive hand work altogether superfluous. Plates up to 15 mm thickness and 150 mm width and of any length can be utilized on this machine, and any desired pitch from $1:\infty$ to about 1:20 can be milled with the mechanical speed regulator. For this purpose the feed screw is driven over a revolution regulator with adjustable speed. With this regulator the feed screw can run forward or backward or be locked. In the latter case, the milled plates will be of constant thickness. Direction of rotation with the cut gives taper, against the cut gives the opposite effect.

The milling cutter operates at 250 and at 450 m/min. cutting speeds. It has a two-speed feed. The higher stage 1 m/min. is for roughing down, the other for finishing. The thickness of the chip properly ranges between 0.5 and 0.8 mm for roughing. The feed rollers are interchangeable and can be exchanged for section rollers. For example, angle sections with shanks up to 30 mm can be milled.

Samples from this machine are:

Duraluminum fitting plate, 4 x 100 x 2,720, thinned down to 1.5 mm at both ends for a distance of 200 mm;

A 15 x 126 x 4,112 mm plate of the same metal thinned down over its entire length of 15 mm to 2.5 mm.

The finished product has an unobjectionably smooth surface and requires no finishing by hand.

VI. DRILLING AND COUNTERSINKING TOOLS FOR MOUNTING STANDARD PARTS

Small pieces with several fitted holes, such as riveted nuts, cowling catches, etc., are numerous in every airplane. Since the holes have been largely standardized, the multiple drill developed by the Heinkel Company shops is very practical. They are simply attached to the conventional drills and give the desired attachment holes in one operation (fig. 27).

The covers and lids, etc., fastened on wings with riveted nuts, etc., must, if they have to transmit stresses, be reamed or countersunk together with their support in order to assure proper contact of the bolt or countersunk screw. The Heinkel Company has developed a countersinking milling cutter for this work (fig. 28). The spindle is screwed into the previously riveted nut and presses the layers tightly together. The milling cutter turns freely around the spindle and is driven by an ordinary machine drill. The feed is maintained by a hand lever with adjustable stop. This tool affords not merely proper contact of the countersunk screw but also a consistently identical depression, the axis of which is coincident with that of the screw thread.

VII. TOOLS FOR CREASING THIN SHEET

This tool simply consists of two ordinary staggered ball bearings. Fastened to the workbench, it insures a clean crease of any length. For creasing edge fairings without enlarging the shanks or for creasing already fitted sheets, a hand-creasing tool had been developed. On it one of the two rollers moves on the eccentric pin of a continuous spindle, so that it can be adjusted according to sheet thickness. The two guide rollers themselves are adjustable.

The same pieces are used in a round creasing tool for crimping the edges of openings especially in repair work. Since the guide rollers are adjustable, the tool is practical for holes of any diameter and width of crease.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

TABLE I. Strength of the Experimental Tubes Before and After Testing - Tensile and Compression Test Data

Rolled Thread		M 12 x 1.5								M 14 x 1.5					
Tube diameter (1 mm-gage)		15	20	25	30	35	39.9	44.8	50	25	30	35	39.9	44.8	50
Length l	mm	300	404	500	584	602	600	602	595	496	606	599	602	599	603
Length l_1.	mm	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	16.5	16.5	16.5	16.5	16.5	16.5
Tensile strength in delivery state $\sigma_{+0.2}$	kg/mm²	37.7	34.0	36.0	29.5	30.1	30.0	30.1	31.8	36.0	29.5	30.1	30.0	30.1	31.8
σ_{+B}	kg/mm²	46.5	46.3	48.8	46.0	44.3	45.1	44.4	46.1	48.8	46.0	44.3	45.1	44.4	46.1
$\sigma_{-0.2}$	kg/mm²	31.2	35.9	35.7	32.1	35.7	36.0	31.4	-	35.7	32.1	35.7	36.0	31.4	-
Tensile strength after test $\sigma_{+0.2}$	kg/mm²	-	28.5	26.2	30.6	31.8	30.6	-	-	26.9	28.1	31.3	30.5	26.2	-
σ_{+B}	kg/mm²	43.5	45.8	41.7	45.3	48.5	46.3	43.8	-	-	44.9	49.5	46.1	43.7	-
$\sigma_{-0.2}$	kg/mm²	33.9	26.6	25.2	27.0	31.1	-	-	27.3	24.0	27.8	31.9	-	-	25.4
Number of heat treatments after finishing process		-	-	1	1	1	2	3	3	1	1	1	2	2	3
Buckling load.	kg	900	1100	1200	2050	2300	2300	2475	2750	1425	1850	2450	2200	2600	3000
Failing load in tension .	kg	900	1450	1625	2700	3090	3200	3310	3550	1925	2650	3050	3250	3550	3600
Area of break.	mm²	26.1	36.8	45.7	66.5	66.5	73.7	78.6	83.6	52.5	60.5	68.2	73.5	87.2	87.2
σ_B	kg/mm²	34.6	39.4	40.4	40.4	46.3	43.5	42.3	45.2	36.6	43.8	44.6	44.3	40.8	41.2

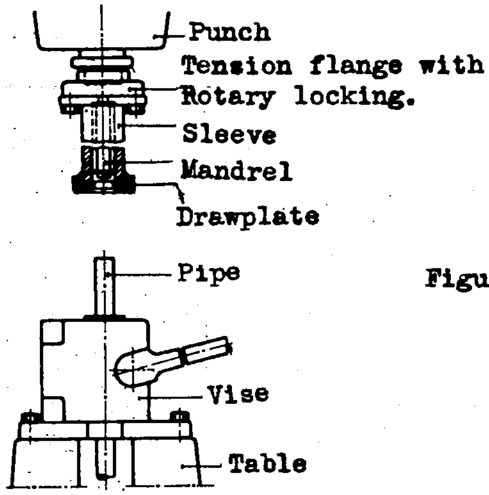


Figure 1.- Outside drawing (or expanding) tool.

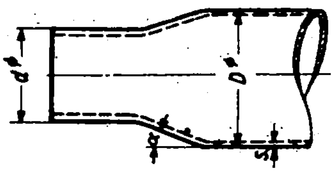


Figure 2.- Contracted thin-walled tube.

Figure 4.- Contracted thin-wall tube.

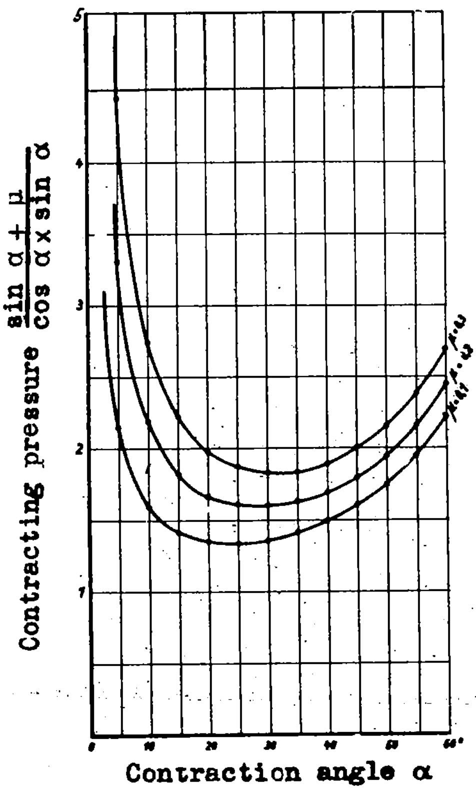


Figure 3.- Effect of contraction angle on the contracting pressure for different coefficients of friction.

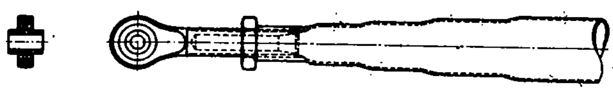
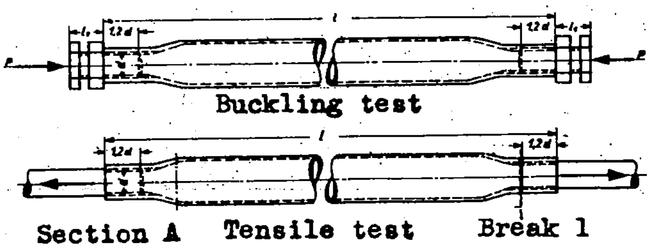


Figure 6.- Push rod with adjustable eye.



Figures 7,8.- Loading arrangement for buckling and tensile tests.

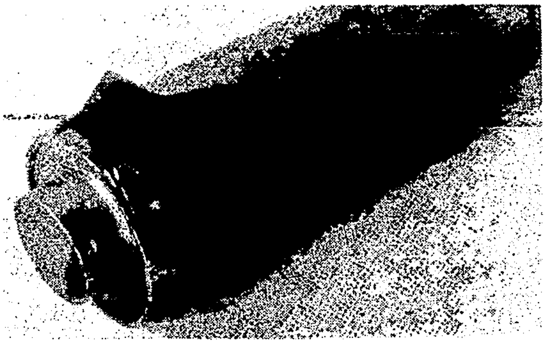


Figure 5.- Test cylinder.

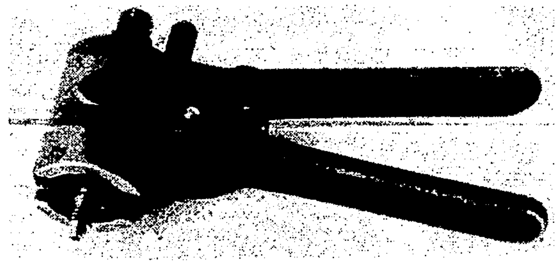


Figure 28.- Countersinking cutter.

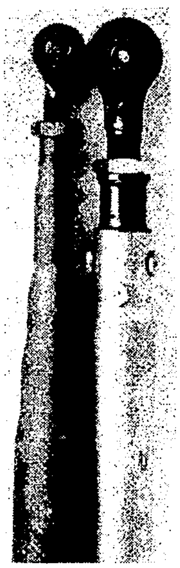


Figure 12.- Tubular duralumin push rod 35 × 1 with self-aligning bearing head, old and new design.

Figure 13.- Flanged duralumin tubes.

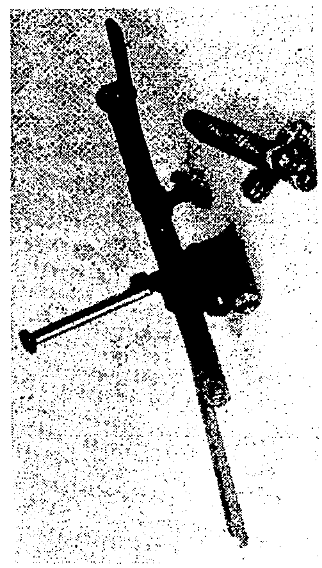


Figure 29.- Hand creasing tool.

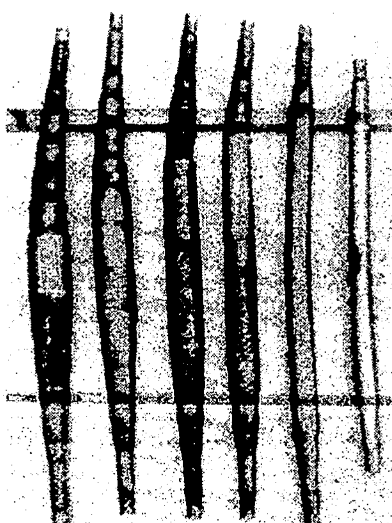


Fig. 10 M 14 × 1.5

Fig. 11 M 12 × 1.5

Figures 10,11.- Failures of a series of test tubes with rolled thread.

Figure 27.- Multi spindle drill inserts for hand drill machine.

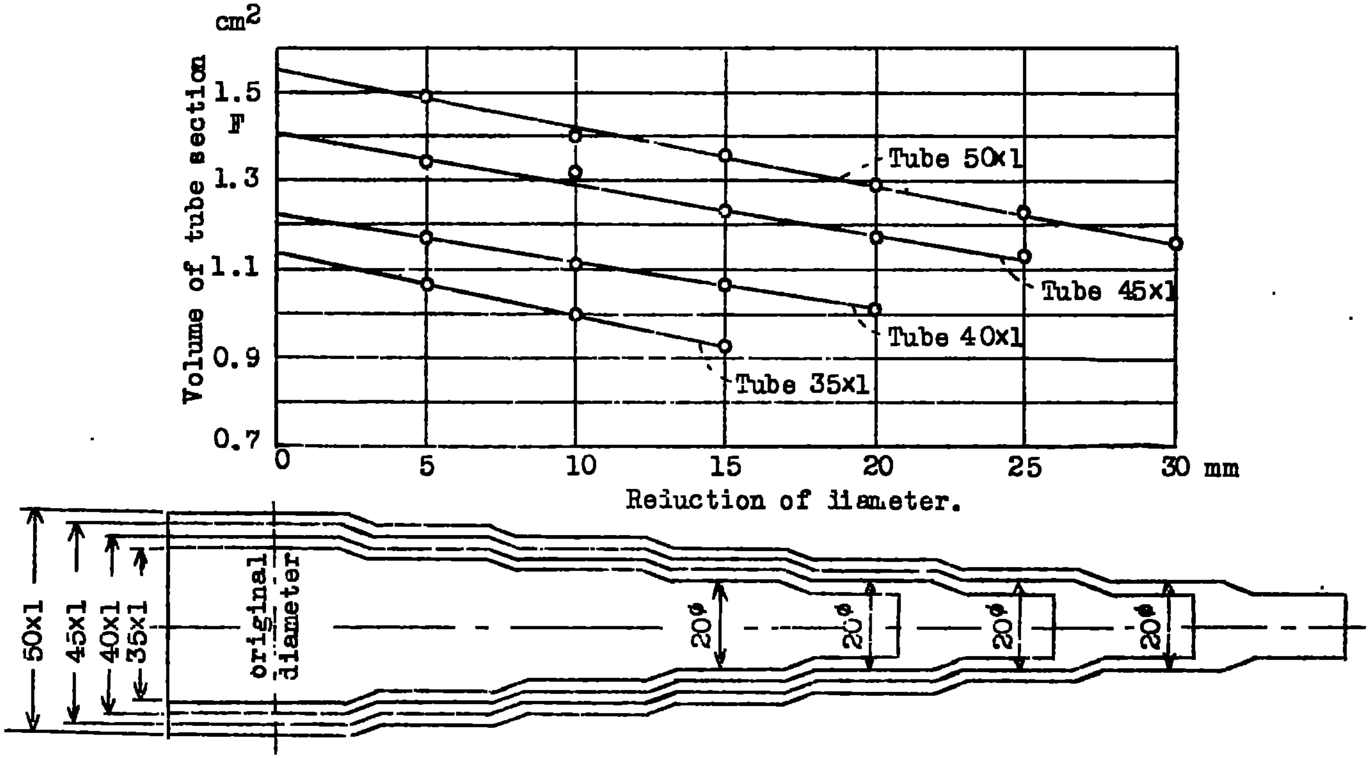
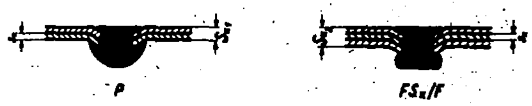
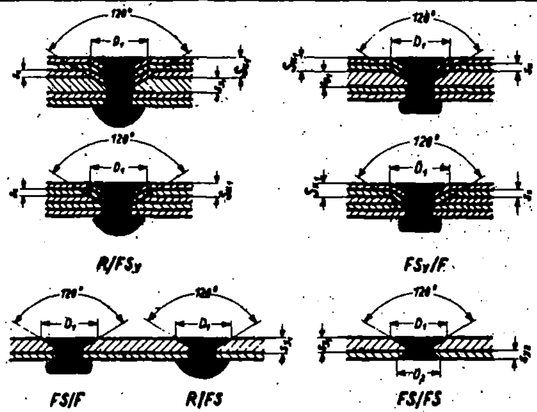
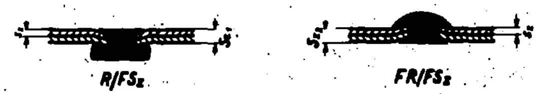


Figure 9.- Cross-sectional change on contracting duralumin tubes of different original diameter to 20 mm diameter.

Construction sizes		Rivet diameter 2	2.6	3	Type of riveting		
Maximum sheet thickness	s_x	1	1.2	1.2			Dimpled sheets (x)
Maximum gripping length	S_{x_1}	1.4	1.8	2.1			
Maximum gripping length	S_{x_2}	2	2.6	3			
Normal sheet thickness	s_{y1}	1.2	1.5	1.8		Thickest sheet counter-sunk	Counter-sunk sheets (y) and flat counter-sunk sheets
Minimum sheet thickness	s_{y1}	1	1.2	1.5			
Countersink diameter	D_1	4.8	5.7	6.5		Counter-sink start 3rd sheet	
Least sheet thickness for second sheet in flap riveting.(hinged plates)	s_{y2}	0.6	0.8	1			
Related countersink diameter	D_2	3.4	4.4	5.2		Outside sheet counter-sunk	
Maximum sheet thickness	s_2	0.6	0.8	1			Dimpled sheets (z)
Maximum gripping length	S_{z_1}	1.4	1.8	2.1			
Maximum gripping length	S_{z2}	1	1.3	1.5			

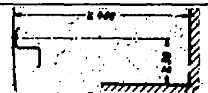
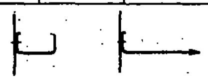
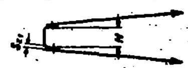
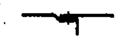
 By unrestricted accessibility: (wings and fuselages) Flat countersunk riveting FS_x/F or FS_y/F ; Mushroom riveting or R/FS_y	 On closed sections, adjoining walls, etc. Flat countersunk riveting, FS_x/F or FS_y/F ;by hand riveting also mushroom riveting, R/FS_y , R/FS_z	 For low clearance FS_x/F for $H \geq 12$; R/FS_z " $H \geq S_{z1}$ 8	 Edge riveting of thin sheets R/FS_z	 For flaps in air stream FS/FS or FR/FS_z

Figure 14.- Skin riveting methods.

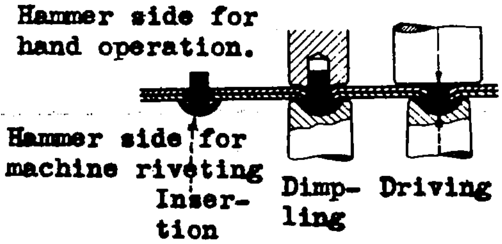


Figure 15.- Mushroom-head riveting.

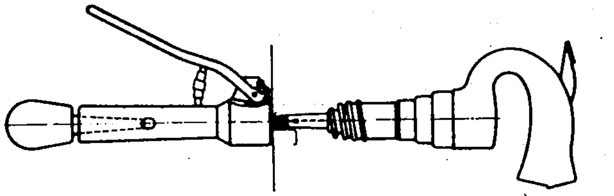


Figure 16.- Mushroom riveting tool. (machine operation).

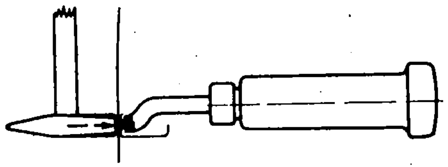


Figure 17.- Dolly with elastic mass and curved set for hand driving.

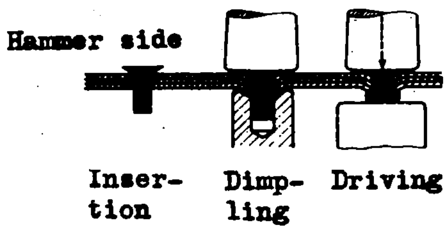
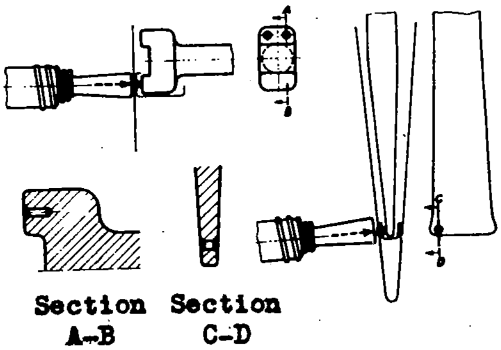
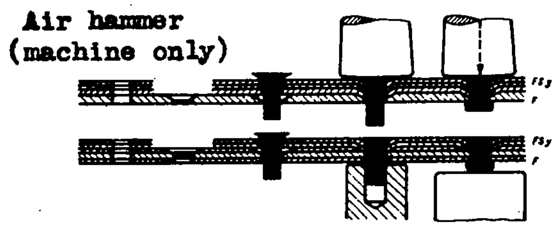


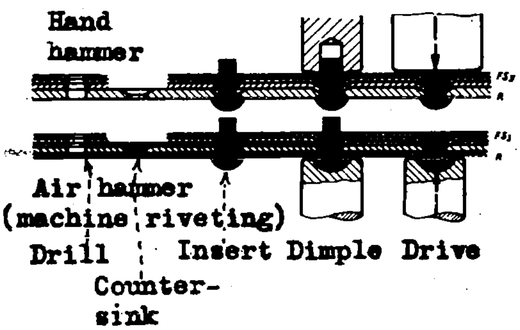
Figure 18.- Flat countersunk riveting.



Figures 19-21.- Flat countersunk for limited accessibility.



Figures 22,23.- Countersunk riveting with flat countersunk rivets.



Figures 24,25.- Countersunk riveting with roundhead rivets.

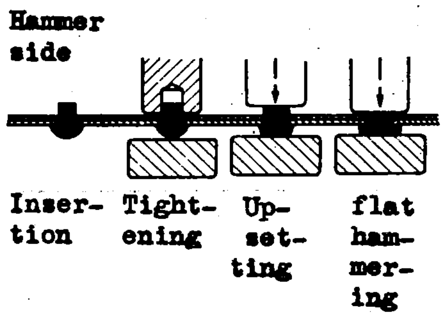


Figure 26.- Riveting with forced-in sheets.